A BEAM ABORT SYSTEM FOR THE DIAMOND-II STORAGE RING

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Abstract

Due to the high energy density of the Diamond-II low-emittance electron beam, the risk of damage to storage ring components is considered high. A dedicated beam abort system is one way to safely dump the beam and protect the machine from damage. In this paper, we present the design of a beam abort system for the Diamond-II storage ring. The requirements of the key components will be described, including the kickers and beam dump. Simulations of the effects of beam loss on the beam dump surface and collimator blades will be shown.

INTRODUCTION

The Diamond-II upgrade is a 3.5 GeV light source facility with 162 pm natural emittance and 300 mA average current. It will generate high brightness synchrotron radiation for users across a range of disciplines [1]. Due to the high energy density of the electron beam, a beam abort system has been found to be essential for safely dumping the beam, either intentionally or due to any type of failure mode that might happen. These include:

- fewer than n RF cavities at field, where n is a configurable parameter
- beam excursion outside the ±250 µm EBPM orbit interlock limits
- loss of the Machine Protection or Personnel Safety Systems (MPS or PSS) permit
- manual beam dumps requested over EPICS

The beam abort system will be enabled for stored beam currents above 10 mA. Injection above this current will only be enabled if all beam abort system components indicate they are 'ready to fire'. The need for an additional beam-instability interlock is also under consideration. If a manual beam dump is requested, the multi-bunch feedback system will be set to first increase the beam emittance before dumping the beam.

DIAMOND-II BEAM ABORT SYSTEM

The Diamond-II beam abort system is composed of the following elements:

- two solid beam dumps (BDs)
- horizontal and vertical kicker magnets
- power supplies to power the kickers
- a beam abort controller

The beam dumps and kickers will be located in the K23 and K24 mid straight sections. In the latest design, each of the straights will contain two 200 mm long horizontal kickers and one 400 mm long vertical kicker. The beam dumps are located downstream of the kickers and consist of a main tapered section with a length of 97 cm and a 10 cm flat section at the downstream end. The horizontal gap changes from ±10 mm at the beginning of the main body to ±5 mm at the flat section. The layout for the K23 straight section is shown in Fig. 1. The main parameters for the kickers are given in Table 1.

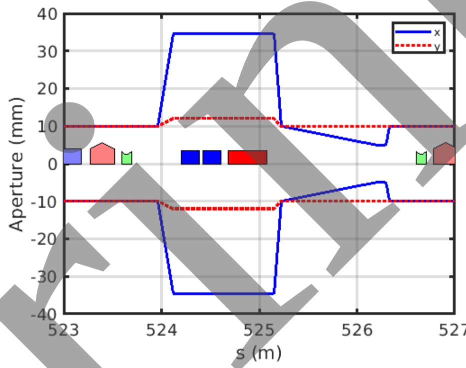

Figure 1: General layout of the beam dump system in K23. The same layout is used for K24.

Table 1: Nominal Parameters for the BD Kickers

Parameter	**Hor. kicker**	**Ver. kicker**
Length (mm)	200	400
Kick angle (mrad)	+2.56	-0.35
Pulse shape	Linear rise	Half-sine
Pulse duration (µs)	3.74	1.87
Peak Field (T)	0.15	0.01

Several waveform shapes and kick angles have been investigated for the kickers to spread the individual electron bunches along the length of the BD as evenly as possible. The results of this study indicated that the optimum waveform for the horizontal kickers is a linear rise as a function of time, increasing the kick angle from zero to a maximum value of +2.56 mrad after two turns. This solution is a trade-off between uniformly distributing the bunches and keeping the design of the power supply simple. The peak magnetic field for the kicker is 0.15 T. The optimum waveform for the vertical kicker was found to be a half sine within one turn with the peak value of -350 µrad. The final kick angles as a function of time are displayed in Fig. 2.

TRACKING RESULTS

The Elegant simulation code [2] was used to track all 934 bunches through the Diamond-II storage ring, including the effects of the beam abort system. Each of the tracked bunches contained 400 macroparticles, and the bunch separation was set to 2 ns.

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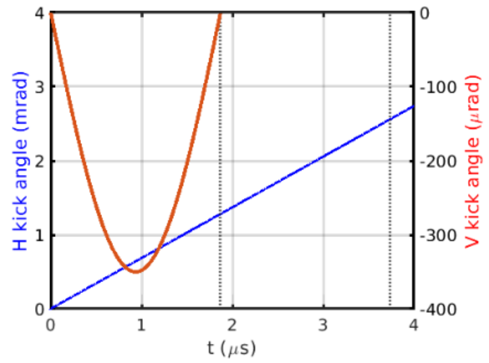

Figure 2: Variation of the horizontal and vertical kicker magnet angles as a function of time.

For the optimised waveforms, all the particles were found to be lost within two turns. 83.7% of the lost particles were lost in the beam dumps (27% in K23 and 56.7% in K24), 8% of the losses were lost on the horizontal collimators and the remaining 8% were lost in the vertical collimators. No losses were observed elsewhere in the ring, showing that all losses occur on components designed to take the beam. Figure 3 summarises which bunches end up in which locations, and 2D histograms of the loss distributions in the beam dumps and collimators are given in Fig. 4. As shown, the losses are uniformly distributed along the beam dump tapered sections. The colour bar indicates the population of the particles.

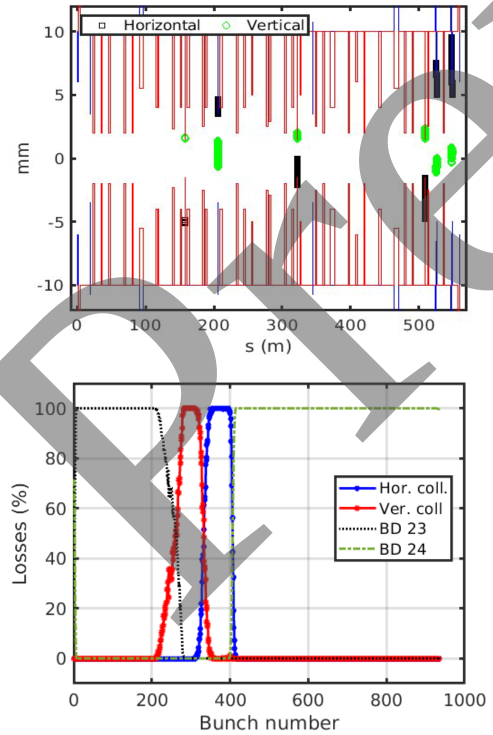

Figure 3: Coordinates of the loss along the ring (top), percentage of losses as a function of bunch number (bottom).

Figure 3 (bottom) indicates that the kick angle for the first ~200 bunches is small enough that they survive to the second turn, eventually being lost in BD 23. Due to the increasing kick angle as a function of time, particles lost in the first turn occur first on the vertical collimators, then the horizontal collimator and finally in BD 24.

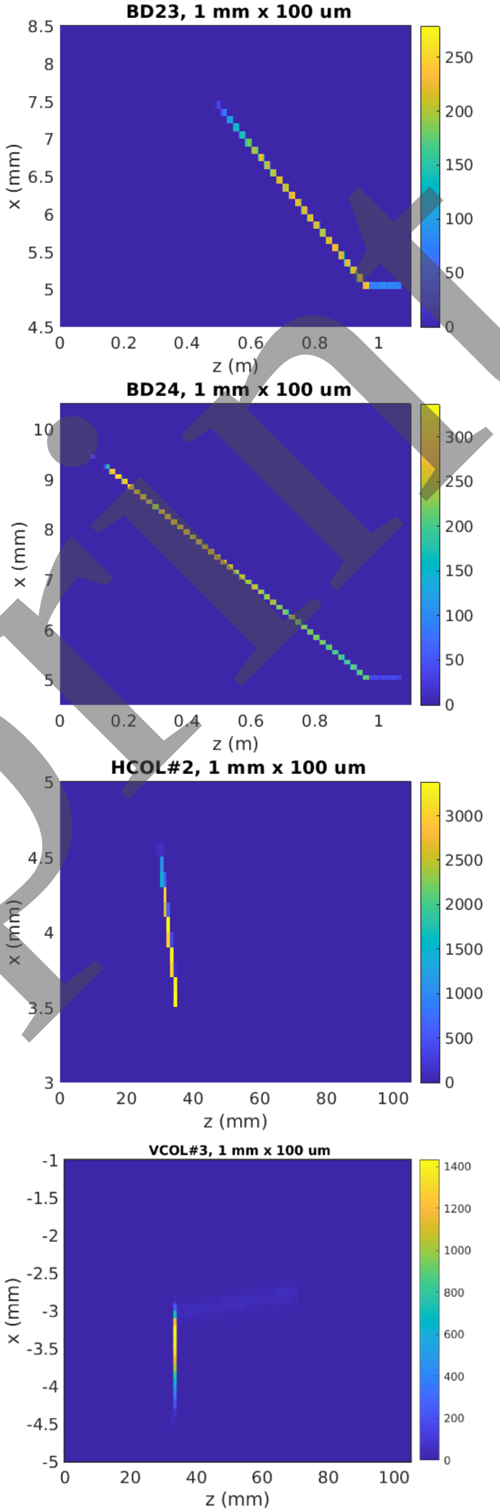

Figure 4: 2D histograms of losses in BD 23, BD 24, horizontal collimator and vertical collimator. Colour bar represents population of particles.

DEPOSITED ENERGY

One of the main goals of the design was to ensure the energy density deposited in the beam dumps and collimators remained below the melting point for copper. For this study, this has been taken to be 3.5 kJ/cm^3, similar to the value used for SLS 2.0 [3]. To determine if this threshold is likely to be reached, calculations using BDSIM [4] have been performed. The models used for the beam dump and collimators are shown in Fig. 5. The collimators blades have a cooled copper section at the entrance to take the incident synchrotron radiation and heavy alloy tungsten behind to absorb the EM shower. The beam dump is assumed to be made of copper.

The particle loss distributions found from the Elegant studies were imported directly into BDSIM. The mesh size was chosen to correspond to the electron bunch size in the relevant component. For the BD, the horizontal and vertical beam sizes are 30 μm and 4 μm respectively, and in the collimators they are 67 μm and 7.2 μm. The total deposited energy per electron is shown in Fig. 6 for each location. The energy density for a uniform filling pattern and for a 3nC single bunch are shown in Fig. 7 for the beam dump and collimators. As can be seen, the maximum value for the energy density deposited in the elements is expected to remain well below the target value.

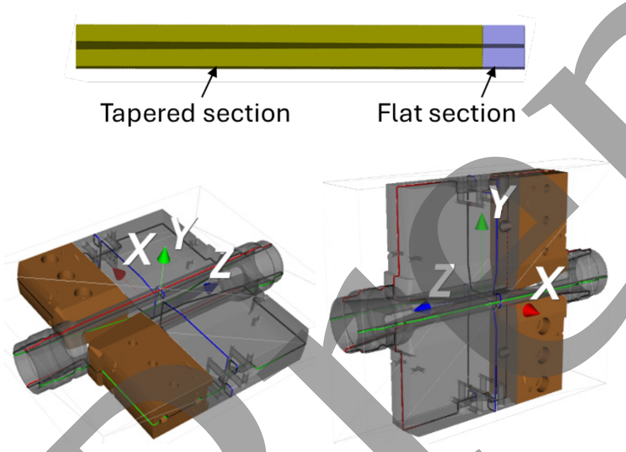

Figure 5: Beam dump (top), horizontal (bottom left) and vertical (bottom right) collimator models used in BDSIM.

CONCLUSIONS

Initial studies for a beam abort system for Diamond-II have been completed. An outline specification has been developed, detailing how the system should respond to various types of beam loss mechanism. Requirements on the individual components have been defined, and a first assessment has been made for the risk of damage to individual components. Next steps are to complete the detailed design work for the individual system components.

The authors would like to thank all members of the Diamond-II beam dump working group for contributions to this study.

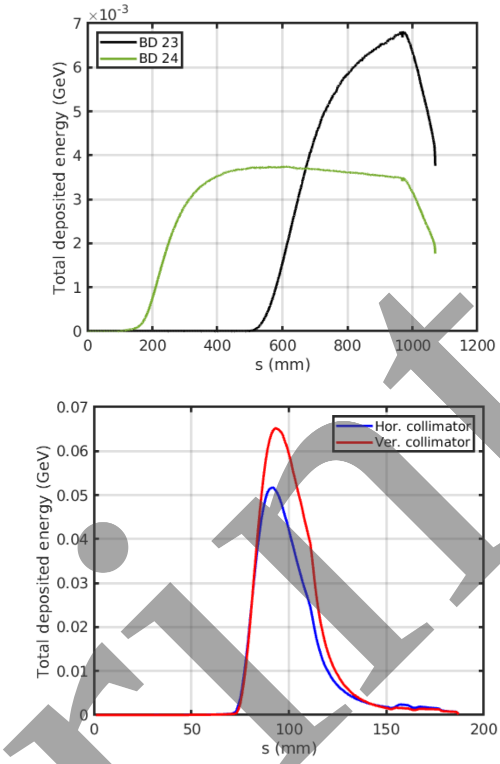

Figure 6: Deposited energy per electron along the length of BDs (top) and collimators (bottom).

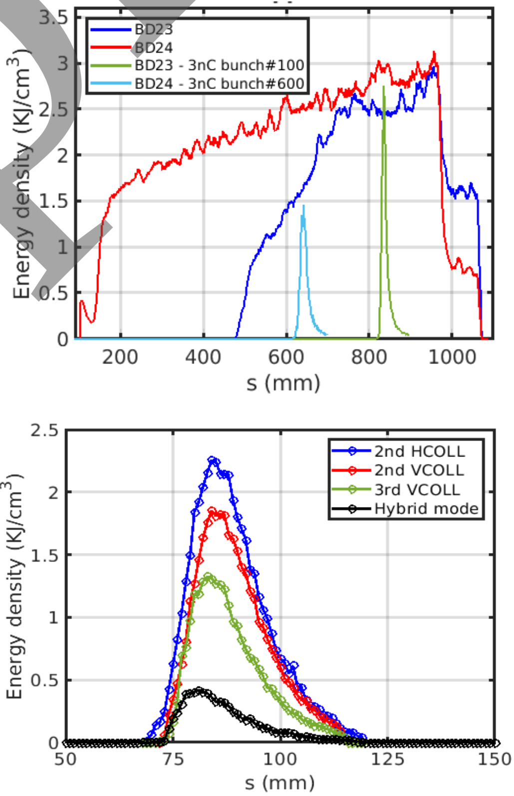

Figure 7: Energy density along beam dump (top) and collimator (bottom).

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